Second Sound Measurements Very Near The Lambda Point

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Abstract

High resolution measurements of the second sound velocity near T_λ in superfluid ^{4}He at the vapor pressure are reported. Experiments were performed using the resonant technique in cavities 13 mm, 4 mm and 2 mm in height. A disc of paramagnetic salt, copper ammonium bromide, in direct contact with the helium sample and coupled to a SQUID magnetometer, was used as the sensor. The sound was generated by wire-wound heaters embedded in the end opposite the sensor in each cavity. The superfluid density was determined from second sound measurements and the critical exponent ν was obtained from fits to the data. The results for the exponent were found to be very sensitive to the treatment of systematic effects in the data.

Keywords: second sound; superfluid ^{4}He; lambda point

Powerful tests of the renormalization group (RG) theory can be performed near the superfluid transition in ^{4}He. Measurements of the second sound velocity, and hence the superfluid density, give rise to an experimental evaluation of the critical exponent ν which describes the critical behavior of the correlation length in the superfluid. The equation for the second sound velocity, U, is given by

$$U^2 = TS^2\rho_s/C_p\rho_n, \tag{1}$$

where ρ_s and ρ_n are the superfluid and the normal fluid densities, T is the temperature, S is the entropy, and C_p is the specific heat at constant pressure. The critical behavior of the superfluid density can be described by

$$\rho_s = [k_0(1 + k_1 t)]t^\nu(1 + D_\rho t^\Delta). \tag{2}$$

The coefficients k_0, k_1 and D_ρ are determined by fits to experimental data and t is the reduced temperature, $t = 1 - T/T_\lambda$. The critical exponents ν and Δ are predicted by RG theory and can also be determined by fitting to the experimental data. This paper presents second sound velocity measurements from three resonators of varying lengths. Data were taken within the reduced temperature range of $10^{-7} < t < 10^{-2}$.

Second sound data were taken in resonators of lengths 13 mm, 4 mm and 2 mm with diameters of 4.75 mm, 2 mm and 2 mm, respectively. The resonators were of epoxy construction, with wire wound heaters located at the bottom of the cell. The paramagnetic salt, copper ammonium bromide (CAB), was used as the sensing element for all the resonators. A packed powder pill (13 mm

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cell) [1] and single crystals (4 mm and 2 mm cells) of CAB were epoxied in the top of the cells and were in direct contact with the helium sample. Second sound was generated by applying an AC signal to the heater, creating a standing temperature wave in the cell. The temperature was read out by a SQUID magnetometer coupled to the CAB sensor with a superconducting pickup coil. The resonators were thermally anchored to the final stage of a four stage thermal isolation system cooled to 2.0 K.

Multiple, closely spaced, second sound resonances were found while taking data in the 2 mm and 4 mm cells. As the resonance curve for a given temperature was measured, several strong peaks were observed. The location and amplitude of these extra peaks varied with reduced temperature and were present in data from $10^{-6} < t < 10^{-2}$. The extra modes appear to be due to second sound excitations in the fill line. As the lambda transition was approached, and the fluid in the narrow fill line was driven normal by the small heat current, the extra modes disappeared. A model of the full system geometry, including the cell and the fill line, was developed. The analysis predicted the qualitative changes in the amplitude and frequency spacing of the extra modes as the effective geometry of the system changed with temperature. Evidence for the multiple modes was also found for the 13 mm cell upon reexamination of the data. However, since the size of this cell was significantly larger than the other two, the effect of the fill line was much smaller, and the multiple modes were found to affect data only in the narrow reduced temperature range of 7–9x10^{-4}.

In the case of multiple modes, the resonance curve contains a "main" mode and several "satellite" modes. The difficulty arises from the fact that the "main" mode identified does not necessarily correspond to the resonant frequency in the cell without the fill line. Correcting for this shift was very difficult. The residuals plot in figure 1 shows the deviation of the second sound velocity data from fits to equation (2). These data show statistical scatter in the multiple mode region of less

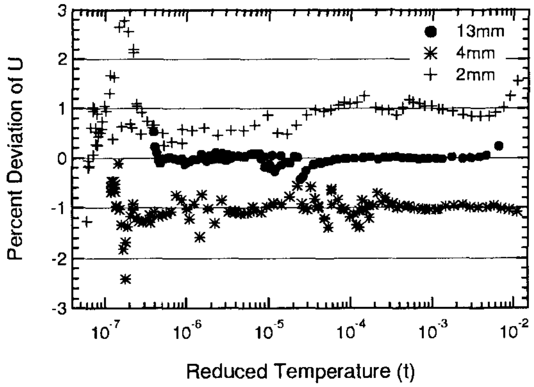

Fig. 1. Residuals plot for data and fit function described in text. Data for the 2 mm and 4 mm cells have each been offset by 1% for clarity. The reduced temperature t is referenced to the middle of the cells.

than 0.1%. However, there are systematic discontinuities in the data due to the extra modes and appear as jumps of up to 1% in the deviation plot. These discontinuities could only be corrected to about 0.5%.

The data in the 13 mm cell, initially reported in [2], were fit to equation (2), with the small region of multiple mode data deweighted. The resulting critical exponent was $\nu = 0.66758 \pm 0.00006$. Exponents for the 2 mm and 4 mm cell data were $\nu = 0.6733 \pm 0.0002$ and $\nu = 0.6739 \pm 0.0001$, respectively. Previous work by Goldner, et. al. [3], measuring second sound velocities using pulse techniques, obtained an exponent $\nu = 0.6705 \pm 0.0006$. It is believed that the small differences in the exponents are due to systematic effects from the extra modes, and possibly from small errors in the temperature scale calibration.

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